A Search for Extragalactic Methanol Masers

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Abstract

A sensitive search for 6.7–GHz methanol maser emission has been made towards 10 galaxies that have yielded detectable microwave molecular–line transitions. These include several which show OH megamaser or superluminous H_2O maser emission. Within the Galaxy, CH_3OH and OH masers often occur in the same star formation regions and, in most cases, the CH_3OH masers have a greater peak flux density than their OH counterparts. Thus we might expect CH_3OH masers to be associated with extragalactic OH maser sources. We failed to detect any emission or absorption above our 60–mJy detection limit. We conclude that if the physical conditions exist to produce CH_3OH megamaser emission, they are incompatible with the conditions which produce OH megamaser emission.

Introduction

OH maser emission in galaxies other than our own was first detected 20 years ago (Whiteoak & Gardner 1973). Since then, extragalactic maser emission has been detected from three other molecules, H_2O, H_2CO and CH (Churchwell et al. 1977; Baan, Güsten & Haschick 1986; Baan et al. 1990; Whiteoak, Gardner & Höglund 1980). In most cases the extragalactic masers seem to be far stronger versions of Galactic masers. However, the OH molecule has also been found to exhibit a different class of maser emission. Megamaser galaxies, first discovered by Baan, Wood & Haschick (1982), are galaxies in which a substantial fraction of the molecular gas surrounding the nucleus is stimulated to emit maser radiation, so that the galaxy as a whole appears as a maser some million times more luminous than a normal Galactic maser. Where they occur, H_2CO emission appears to be associated with OH megamasers, and CH with superluminous H_2O masers.

In recent years, strong maser emission in our Galaxy has been discovered in the 12.2–GHz 2_0-3_{-1} E and 6.7–GHz 5_1-6_0 A^+ transitions of CH_3OH (Batrla et al. 1987; Menten 1991). So far, maser emission has only been detected towards star-formation regions, although

absorption has been detected towards both these regions and cold clouds (Walmsley et al. 1988; Peng & Whiteoak 1991). CH_3OH masers appear to be closely associated with OH and H_2O masers (Norris et al. 1993; Menten et al. 1993) and, in at least one case, the CH_3OH and OH masers are coincident within 2 arcsec, or 4000 AU. Since the same conditions appear to produce both OH and CH_3OH masers, we might expect OH megamaser emission to be accompanied by detectable CH_3OH maser or megamaser emission.

A preliminary search for the 12.2–GHz CH_3OH transition was made by Norris et al. (1987) towards a few known OH megamaser galaxies, but no systematic sensitive search has been published so far. Here we present the results of an exploratory search, made at the stronger 6.7–GHz transition.

Observations

The observations were made between 1992 February 25 and March 9 using the dual–channel cooled HEMT 6.7/12.2–GHz receiver at the Parkes 64–m telescope which, at 6.7 GHz, has a beamwidth of 3.3 arcmin. The equivalent system temperature for the observations was $\sim$ 60 K. An autocorrelator provided two 512–channel spectra in orthogonal linear polarizations, each spread over 64 MHz. Thus the observations covered a velocity extent of $\sim$ 2800 km s^{-1} and had a velocity resolution (after Hanning smoothing) of 7.8 km s^{-1}. The spectra were obtained by taking two 10–min spectra on–source and two reference spectra, one offset by +15 min and the other by -15 min of right ascension. These were then used to produce two quotient spectra each with different references, yielding a total on–source time of 20 min. The resulting spectra for the two polarizations were then averaged and Hanning smoothed. The resulting rms noise level of a 10–min observation was typically 0.04 Jy. To achieve the desired sensitivity, multiple observations were made of each source. The total integration time for most sources was 20–40 min, but sometimes exceeded 1 hr; the resulting 3σ detection level was typically no greater than 0.06 Jy.

Flux density calibration was carried out using observations of the sources PKS 0407-658, Hydra A and PKS 1934-638, which were assumed to have flux densities of 2.19, 4.09 and 9.84 Jy respectively.

Ten galaxies were surveyed for the 5_1-6_0 A^+ CH_3OH transition ; six are known OH maser or megamaser sources (Whiteoak & Gardner 1973; Norris et al. 1989; Kazès et al. 1990) and two are known superluminous H_2O masers (Whiteoak & Gardner 1986). Thus the sample is strongly biased towards galaxies which show ultraluminous maser emission in other transitions.

Results

Our results are shown in Table 1. None of the ten galaxies observed contains a detectable 6.7-GHz CH_3OH maser.

The detection threshold of 60 mJy is significantly lower than that necessary to detect the OH and H_2O masers which exist in these sources. Given that the Galactic CH_3OH masers are typically much stronger than Galactic OH masers, this detection limit places a severe constraint on any CH_3OH maser emission, and demonstrates that the OH megamaser emission and superluminous H_2O maser emission are not accompanied by corresponding CH_3OH megamaser emission.

Discussion

In our Galaxy, 6.7-GHz CH_3OH masers are found solely in star formation regions, and are closely associated with OH and H_2O masers. Existing surveys (J. L. Caswell et al. in preparation) indicate that nearly all known OH masers are accompanied by 6.7–GHz CH_3OH activity, and vice-versa. 6.7–GHz CH_3OH masers have been detected towards two HII regions in the Large Magellanic Cloud (Sinclair et al. 1992), S. P. Ellingsen et al.

in preparation). The intrinsic peak flux density of these sources is of a similar strength to most Galactic masers. Since the same conditions appear to produce both OH and CH_3OH masers within the galaxy, we might expect the OH maser and megamaser emission in other galaxies to be accompanied by detectable CH_3OH maser emission, possibly even CH_3OH megamaser emission. Furthermore, in Galactic sources, the 6.7-GHz CH_3OH maser emission is typically much stronger than the corresponding OH emission, and so we might even expect extragalactic CH_3OH maser emission to be much stronger than that of the OH emission. The ratio of the peak flux densities of 6.7–GHz CH_3OH and OH masers spans several orders of magnitude, but is typically of the order of ten. With one exception, the sensitivity of this search would have been sufficient to detect any 6.7–GHz CH_3OH with peak flux density comparable to the OH or H_2O sources observed in these galaxies (see table 1). If we assume that in our sample there are no 6.7–GHz CH_3OH sources with peak flux greater than 3 times the quoted RMS noise level, then we have four sources with CH_3OH : OH flux ratios less than 0.3. Among Galactic masers, approximately 23% have CH_3OH: OH flux ratios less then 0.3, thus if we assume the same CH_3OH : OH flux ratio distribution for extragalactic sources then the probability that any four will all have flux ratios less than 0.3, is 0.28%. Hence it appears extremely unlikely that the extragalactic CH_3OH : OH flux ratio distribution is the same as that observed for Galactic masers.

The differences between Galactic and extragalactic masers sources might be attributed to one of the following causes.

(i) CH_3OH megamasers do not exist, because the physical conditions required to produce them do not exist.

(ii) Extragalactic CH_3OH masers or megamasers do exist, but require different physical conditions from those which produce ultraluminous OH and H_2O maser emission.

(iii) The pumping mechanism or efficiency of CH_3OH masers is such that peak flux density of extragalactic CH_3OH masers is below the detection limit of these

observations.

Megamaser emission requires a number of basic ingredients, such as a sufficient column density of molecules along the line of sight, a means of pumping the masers, and perhaps a background continuum source to provide the input to the maser. Galactic masers appear to require precise physical conditions such as a particular optical depth to the pump radiation. However, megamasers are relatively insensitive to the precise conditions, because the maser activity in these sources is distributed throughout a large region, and a wide range of physical conditions are available if the basic ingredients are present.

Thus our first hypothesis, that CH_3OH megamasers do not exist because the physical conditions required to produce them do not exist, implies that some physical condition is required for methanol maser emission, but that this condition is found only in very special circumstances, and will not be widespread through the disc of a galaxy. An example might be if Galactic CH_3OH masers occur only in concentrations of high density within proto-planetary discs, as suggested by Norris et al. (1993). It is possible that the mechanisms which produce increased CH_3OH density in Galactic star formation regions (Herbst 1991) cannot operate on a sufficiently large scale, or the radiation field in these regions causes depletion by disassociation of the CH_3OH molecules.

Our second hypothesis, that CH_3OH megamasers do exist, but require different physical conditions from those of OH megamasers, would be appropriate if, for example, the CH_3OH masers were radiatively pumped but the OH megamasers collisionally pumped. However, detailed differences, such as optical–depth effects, would not be sufficient to prevent megamaser emission.

The final hypothesis, that the extragalactic methanol masers are below the detection limit of our observations, implies that either the peak flux density of CH_3OH masers cannot greatly exceed that of the strongest Galactic CH_3OH masers, or the conditions which produce ultraluminous Galactic type OH and H_2O masers are not suitable for producing ultraluminous CH_3OH masers. We cannot attribute the non–detection of extragalactic

masers to a deficiency of CH_3OH, as it has been detected towards several galaxies at millimetre wavelengths (Henkel et al. 1987). One of the galaxies which we also observed (NGC 253), was found to have methanol abundances similar to those found in our Galaxy. NGC 253 is also the closest of the observed galaxies, but to detect any masers in our observations, an intrinsic peak flux density at least an order of magnitude greater than the strongest of the Galactic CH_3OH masers would have been required.

All of these cases place a severe constraint on models of CH_3OH maser emission. To determine whether extragalactic CH_3OH masers are common requires a more sensitive and more comprehensive survey.

Conclusion

We conclude that the absence of CH_3OH maser or megamasers implies that either the physical conditions required to produce ultraluminous CH_3OH maser emission are incompatible with those required to produce OH or H_2O emission, or that the ingredients necessary to produce masing in CH_3OH are not present on a large enough scale to produce megamaser emission.

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Table 1. The selected sample of galaxies. References : a, Whiteoak & Gardener (1986); b, Staveley–Smith et al. (1992); c, Baan, Wood & Haschick (1982); d, Bottinelli et al. (1987); e, Whiteoak & Gardner (1973); f, Norris et al. (1989); g, Lépine & dos Santos (1977); h, Dos Santos & Lépine (1979); i, Claussen, Heiligman & Lo (1984)

Source	Position (B1950) Right Ascension h m s	Declination ° ′ ″	Velocity range (km s^{-1})	RMS Flux Density (Jy)	OH Peak Flux (Jy)	H_2OPeak Flux (Jy)	Ref.
NGC 253	00 45 06	-25 34 00	-900→1400	0.01	0.120	5	b,e,g
NGC 1068	02 40 07	-00 13 30	300→2500	0.03	–	0.7	i
NGC 1487	04 04 05	-42 30 42	-300→1900	0.008	–	–	
NGC 1566	04 18 53	-55 03 24	400→2600	0.01	< 0.040	–	f
10039-3338	10 03 55	-33 38 43	9000→11200	0.02	0.315	–	b
11506-3851	11 50 40	-38 51 10	2000→4200	0.01	0.105	–	b
NGC 4418	12 24 23	-00 36 14	1100→3400	0.02	0.004	–	d
NGC 4945	13 02 32	-49 12 02	-600→1700	0.02	-0.800	9→16	a,b,e,h
Circinus	14 09 18	-65 06 19	-600→1700	0.02	–	3→12	a
Arp 220	15 32 47	23 40 10	4300→6500	0.01	0.280	–	c